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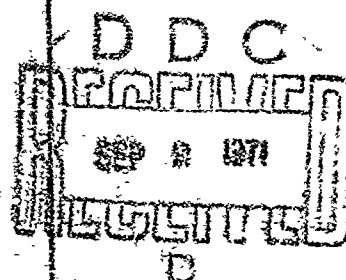
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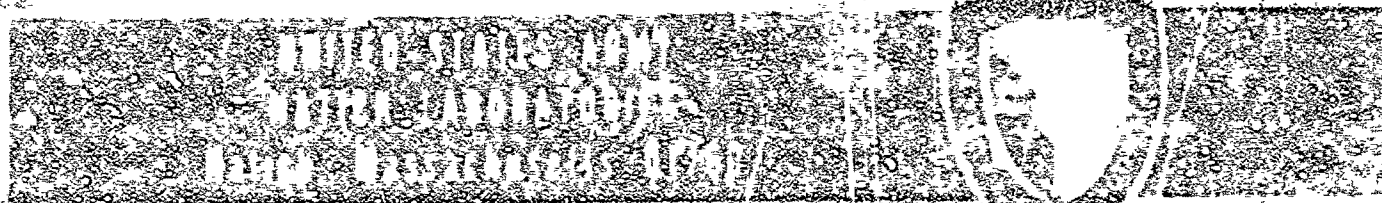
A HISTORY OF THE DEVELOPMENT OF AN
ARMOR ENSEMBLE FOR MINE CLEARANCE PERSONNEL

by

Abraham I. Lustnik



October 1970



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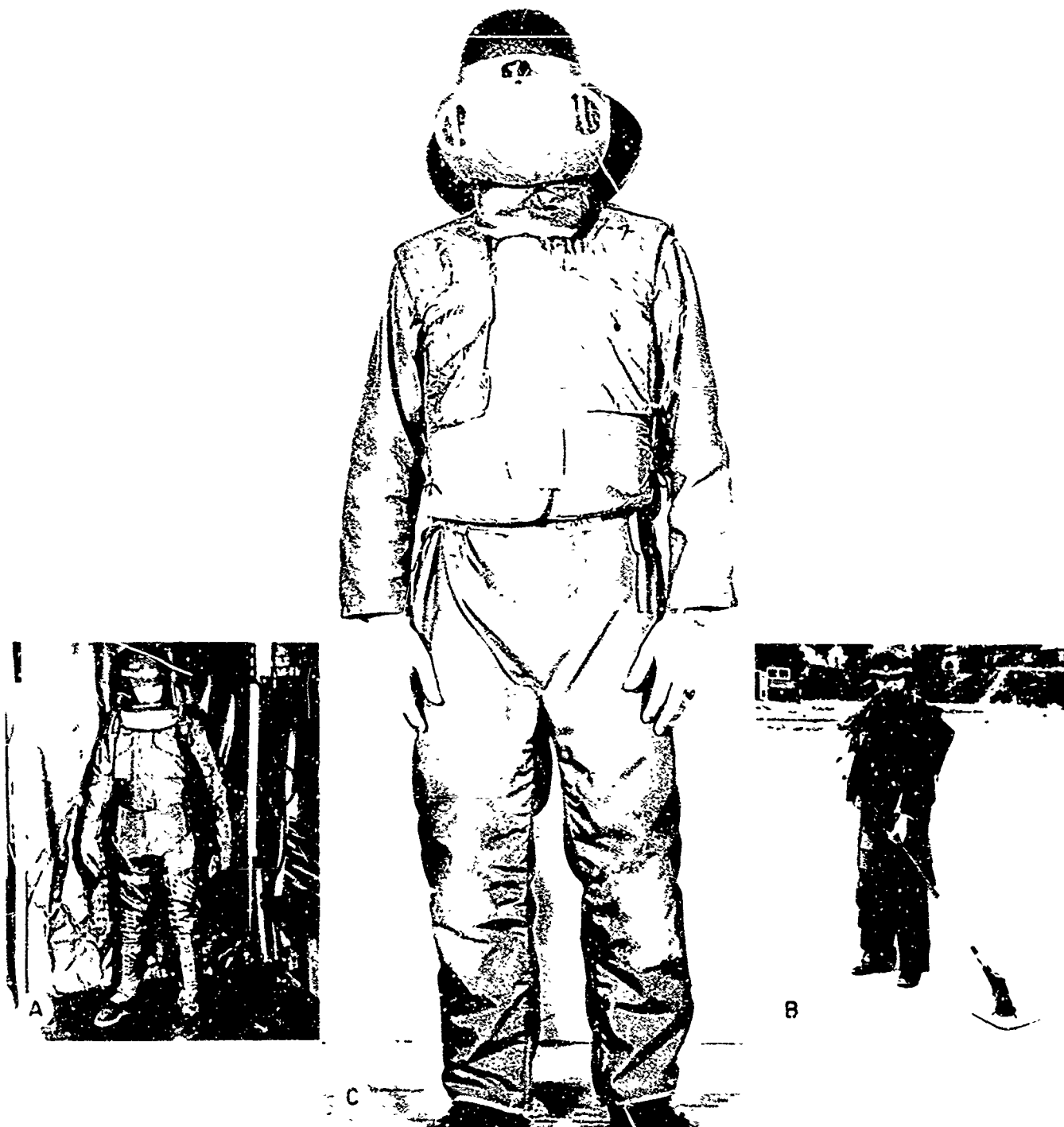
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Clothing and Personal Life Support Equipment Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts



MINE CLEARANCE SUIT

- A. ARMOR (circa 1948) FOR MINES AND DEMOLITIONS
- B. "ARMADILLO" SUIT ASSEMBLED BY TROOPS DURING THE KOREAN WAR FROM SALVAGED LAMINATED GLASS ARMORED PANELS
- C. MINE CLEARANCE ARMOR ENSEMBLE DISCUSSED IN THIS REPORT

FOREWORD

During the late 1950's, these Laboratories developed an armor ensemble to provide protection for mine clearance troops against the effects of anti-personnel mines. The development was successfully completed in that it satisfied all requirements as known at that time. However, advances in anti-personnel mines dictated the need for more sophisticated mine clearance techniques which would reduce the hazards to the mine clearance team, thereby negating the need for total body coverage mine clearance armor.

Since the termination of the mine clearance armor program, these Laboratories have received numerous inquiries regarding the availability of armor for total body coverage. These inquiries were from diverse sources for a variety of uses. The proposed uses for full coverage body armor ranged from wear by munitions handlers to tactical missions by the military, by law enforcement agencies for bomb squad and riot control details, and for industrial safety clothing.

This report reviews the development of the full coverage armor ensemble for mine clearance personnel, highlighting the factors influencing the selection of material, establishment of body area priorities and design. This information is presented so that succeeding developers and users of armor will benefit from the engineering and design experience compiled by the U. S. Army Natick Laboratories.

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ABSTRACT

Mine clearance teams have always tried to adapt available armor clothing to their operations with varying degrees of success. This report is concerned with the history of the development of a full body coverage armor for mine clearance personnel to satisfy military requirements. Discussions are concerned with the hazards of mine clearance, vulnerable body areas, operational concepts, design, protective characteristics and fabrication of the ensemble, and its evaluation. A summary of recent armor material developments and typical applications is included. These materials may be applied to any future concepts for full body armor.

DEVELOPMENT OF ARMOR
FOR
MINE CLEARANCE PERSONNEL

Historical Background

Prior to World War II, armor for mine clearance personnel was not specifically identified under a particular designation. Armor was, however, used by Engineer or Pioneer troops who cleared or traversed mine fields. Body armor of that era was too bulky, too heavy and afforded inadequate protection against mine fragments. Head protection was provided by a helmet; face and eye protection was never satisfactorily obtained.

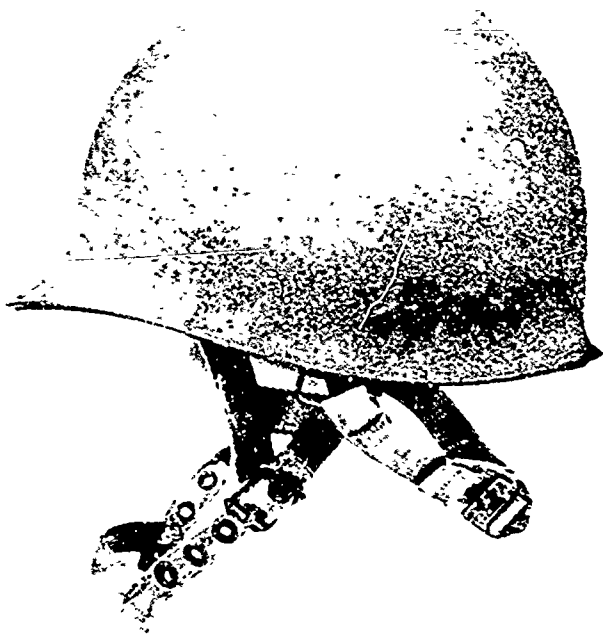
During World War I, armor was designed to protect the neck and shoulders, and a visor fitted to the standard helmet to protect the eyes and face. These items, used with bulky body armor, were too heavy and restrictive to permit general use. Also used during World War I was a slotted metal eye shield similar to the Eskimo snow goggle. This eye shield was attached to the British-American combat helmet of 1918 by springs⁽¹⁾. Other eye protective devices were suggested during World War I, but all were variants of the slotted metal goggles. A few suggested protective goggles were provided as a sort of transparent glass-celluloid laminated safety glass.⁽¹⁾

The World War I armor would, no doubt, have prevented many casualties had it been used. Bashford Dean wrote that armor worn in the field during World War I was usually a commercial article purchased by the individual soldier.⁽¹⁾

With the advent of World War II, interest in personnel armor intensified.⁽²⁾ It was soon apparent to the U.S. Army Infantry Board that the World War I type helmet, originally designed to protect soldiers in trenches from air-burst fragments, was not adequate for a mobile war where missiles and fragments could strike from any direction. Thus, the M-1 steel helmet and M-1 helmet liner were developed⁽³⁾ and made standard on 9 June 1941.

Flak armor, developed and used by the Air Force in World War II, in combination with the M-1 helmet assembly, was evaluated by the Corps of Engineers for use by mine clearance personnel. The flak armor was rejected because its clumsiness, bulkiness and excessive weight made it impossible for mine clearance troops to accomplish their mission.

In December 1944, the Ordnance Corps initiated a project to develop eye defenses against anti-personnel mines. Because of the urgent need for this protection, the Office of the Surgeon General requested that eye defenses be procured as soon as possible with formal requirements to be established later.



STEEL HELMET AND
LINER ASSEMBLY



STEEL EYE ARMOR



ARMORED VEST M1952 MADE FROM
PLIED NYLON FABRIC

FIG. 1 ARMOR MATERIEL
AVAILABLE TO MINE
CLEARANCE TROOPS
CIRCA 1956.

After many unsuccessful attempts, the T45E6 armored goggle was made standard as the M-14 Eye Armor Goggle (4). This eye protective device is a Hadfield steel shield which is pierced by a pattern of narrow horizontal slits over each eye. This shield was contained by a rubber dust goggle frame.

With the end of World War II, the interest in armor decreased and its development was virtually halted. In 1947, the responsibility for the development of personnel armor was transferred from the Ordnance Corps to the Quartermaster Corps. (5)

Introduction

A requirement existed in Combat Development Objective Guide (6) to provide armor for the protection of mine clearance personnel from fragments of exploding mines.

The Military Characteristics (7), developed by the Continental Army Command (CONARC) required that armor for mine clearance personnel provide, in addition to all the characteristics attributed to the Armored Vest, the following:

1. Maximum fragmentation protection possible to the body in its entirety.
2. Compatibility with standard combat clothing.
3. A weight of no more than 20 pounds.
4. A device for attachment to the feet so that personnel could operate over mine fields without causing the detonation of mines by distributing pressure of body weight over a large area.

A review of standard and experimental items (in 1956) uncovered the following components (Figure 1):

1. Steel Helmet
2. Helmet Liner
3. Armored Vest
4. Eye Armor.

Records were also found of a device developed by the Corps of Engineers that would permit troops to traverse mine fields. It consisted of a wide pad similar to a bear-paw type snowshoe, worn attached to the combat boot. As with the bear-paw snowshoe, the anti-mine pads would distribute the body weight over a large area thereby permitting the user to traverse a mine field in relative safety. Their bulk and large size, however, interfered with the utilization of mine detectors. They also made it difficult to locate and to avoid trip wires. Assuming and arising from a kneeling and prone position were extremely difficult, if not impossible, while wearing these devices.



FIG. 2 MINE CLEARANCE SABOT ANTIPERSONNEL MINE FOOT PRO-TECTIVE DEVICE DEVELOPED BY THE U.S. NAVY AND TESTED BY THE U.S. MARINE CORPS.

CONARC would not accept the devices and subsequently withdrew the requirement for foot protection from the military characteristics for armor for mine clearance personnel (8) and later reinstituted the requirement without furnishing details regarding expected performance. (9)

The U. S. Navy also developed an anti-mine foot protective device. This footgear (Fig. 2) was extensively tested by the U.S. Marine Corps. (10)(11)(12)(13) These evaluations indicated that the device would protect the foot from the Brissance effect (blast effect) from concussion type anti-personnel mines. Although the footgear was not intended to defeat fragments, it was conceivable that it could be constructed of armor materials, thus incorporating a measure of fragmentation protection.

Personnel armor available in the supply system (Fig. 1) for application to the protection of mine clearance personnel would cover the following areas:

1. Helmet: protects the head exclusive of the neck, face and eyes.
2. M-14 Eye Armor: protects the eyes but restricts vision.
3. Armored Vest: protects the upper torso and carotid arteries in the neck.
4. Marine Corps anti-mine Sabot: protects the feet from the blast effects of concussion type anti-personnel mines.

At this time the task of analyzing the mine clearance operation, the hazard, the protection required, and integration of standard items into a protective ensemble, was initiated.

Hazards and Body Vulnerability

Before starting the design and fabrication of armor for mine clearance personnel, conforming with the military characteristics, (7) information was required regarding the nature of the fragmentation hazard and its dispersion. Also required was a priority listing of the vulnerable areas of the body.

Guidance from the Surgeon General's Office (14) confirmed information derived from a study of wound ballistics data compiled in the Korean War. (15) (16) (17) The regional frequency of wounds indicated that the vulnerable body areas require protection in the following order of importance regarding vulnerability and lethality.

1. Torso
2. Head and neck
3. Abdomen and groin
4. Extremities.

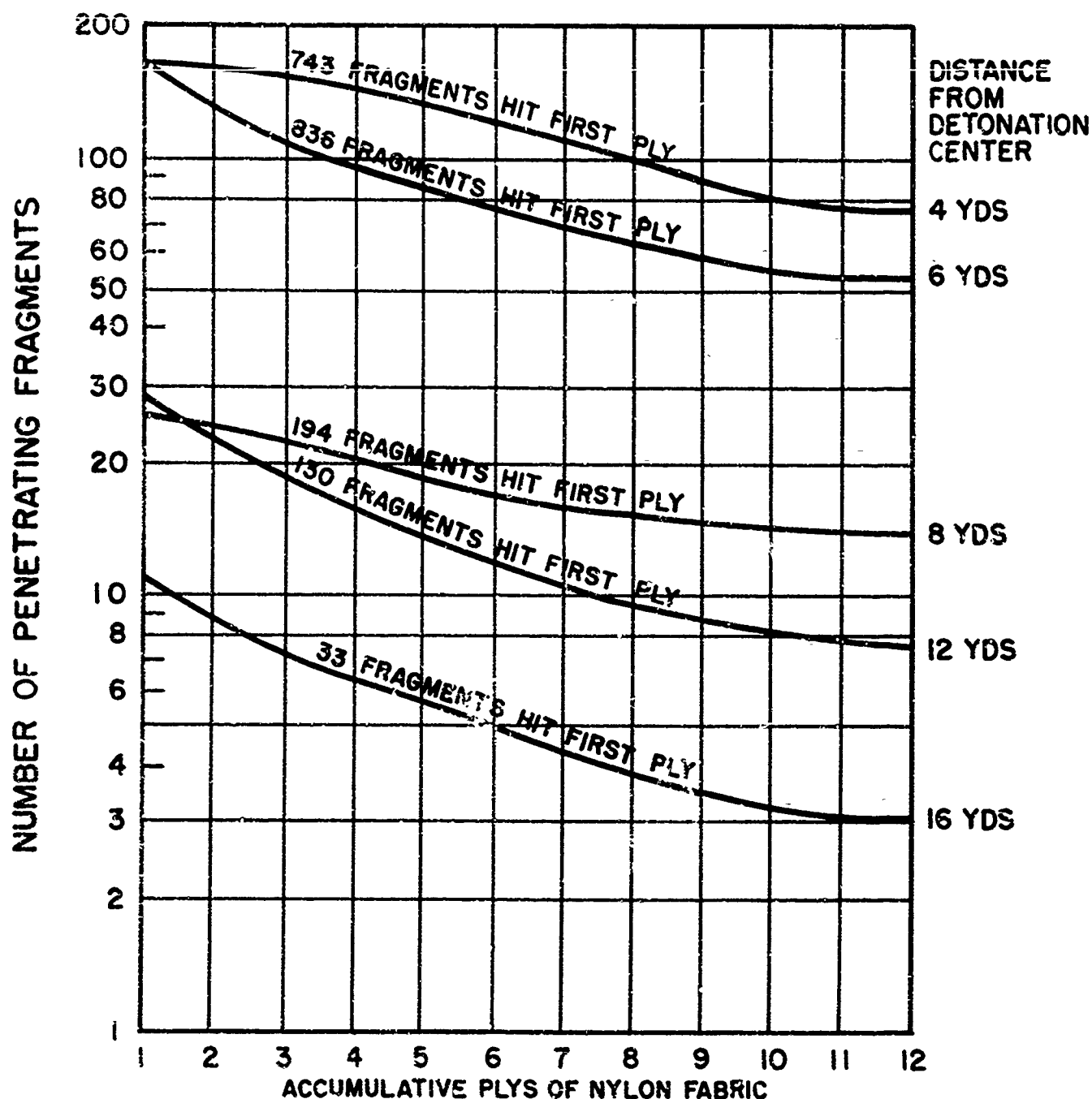


FIG. 3 PENETRATION OF FRAGMENTS FROM A TYPICAL M16 ANTI-PERSONNEL MINE THROUGH A TYPICAL 12-PLY NYLON ARMOR PANEL.

The Quartermaster Corps, with the cooperation of the Corps of Engineers, conducted a series of tests to determine the nature of the hazard presented by exploding anti-personnel mines (18) (19). These studies established the fact that exploding mines would scatter a uniform distribution of fragments over a 2 x 6 foot target. Figure 3 shows how many fragments of the M16 anti-personnel mine may be stopped by each layer of 12 ply nylon fabric armor. Figure 4 shows a typical grouping of a fragmented M16 anti-personnel mine; thus, it was ascertained that the head and face area would require as much protection as any other part of the body. Also established was the number of layers of nylon armor fabric which would provide resistance to penetration of fragments from exploding mines. Figure 5 shows a reduction of data collected by exploding a variety of anti-personnel mines. (18) (19) The plot is a means of the data which considers all mines exploded, including several Russian mines, and all fragments stopped by all layers of all nylon fabric targets which were spaced from 4 feet to 32 feet from the exploding mine. The curve shows the percentage of fragments stopped by accumulative layers of ballistic nylon fabric. This percentage is based upon the assumption that the first layer of nylon fabric did not stop any fragments. Thus, if one layer did not stop any fragments, two layers of fabric will then stop approximately 23 percent of all fragments penetrating the first layer, and the third ply of nylon fabric stopped approximately 10 percent of all fragments penetrating the first layer. In reality, the protective characteristics of the armor are greater than indicated by the chart because the first layer of fabric defeated an undeterminable number of small fragments. This information, except for a concept of use, provided the tools required to proceed with the development of armor for mine clearance personnel.

Operational Concepts

The weight and bulk of available armor materials which will provide total protection from anti-personnel mine fragments is so great that it would immobilize an individual, even if a flexible garment could be fabricated. Thus, the mine clearance armor ensemble was designed to provide maximum fragmentation protection possible in the most vital body areas without compromising the operational functionality of mine clearance personnel.

It must be emphasized that "maximum protection", as applied to the mine clearance ensemble, does not mean total protection. An individual wearing the mine clearance ensemble and operating within four yards of a detonated fragmentation mine would probably suffer fatal wounds. As the distance increases from the fatal four-yard radius, the probability of fatal wounding or the penetration of the armor decreases.

Because armor specifically intended for mine clearance personnel had never been a standard item in the Army supply system, doctrine or concepts of use have not been developed. As a result of experience gained in the development and testing of mine clearance ensemble, the following recommendations are offered for consideration when formulating the logistical and use concept of the ensemble.

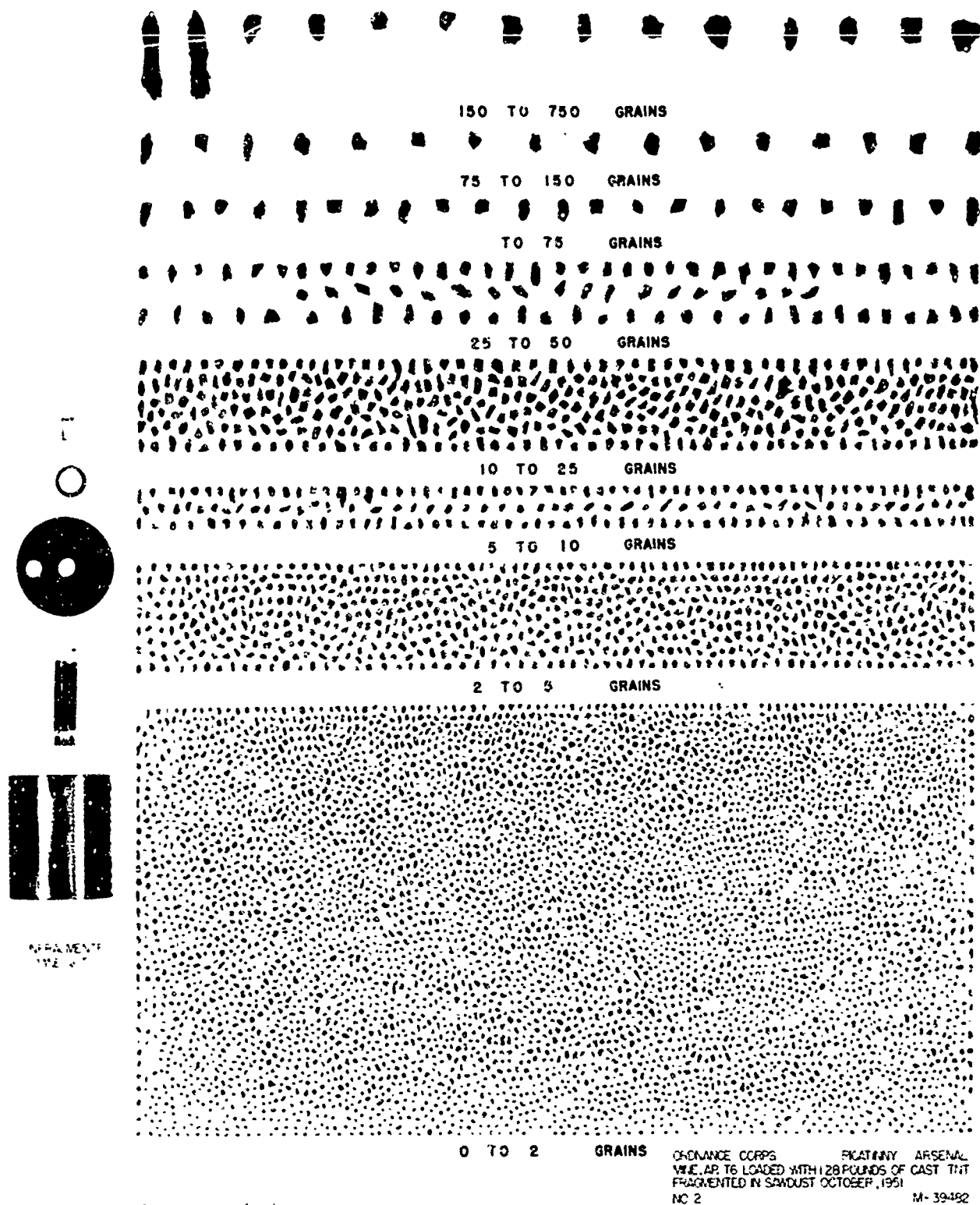


FIG. 4 TYPICAL FRAGMENT GROUPING OF AN M16 ANTIPERSONNEL MINE FRAGMENTED IN SAW-DUST BY PICATINNY ARSENAL.

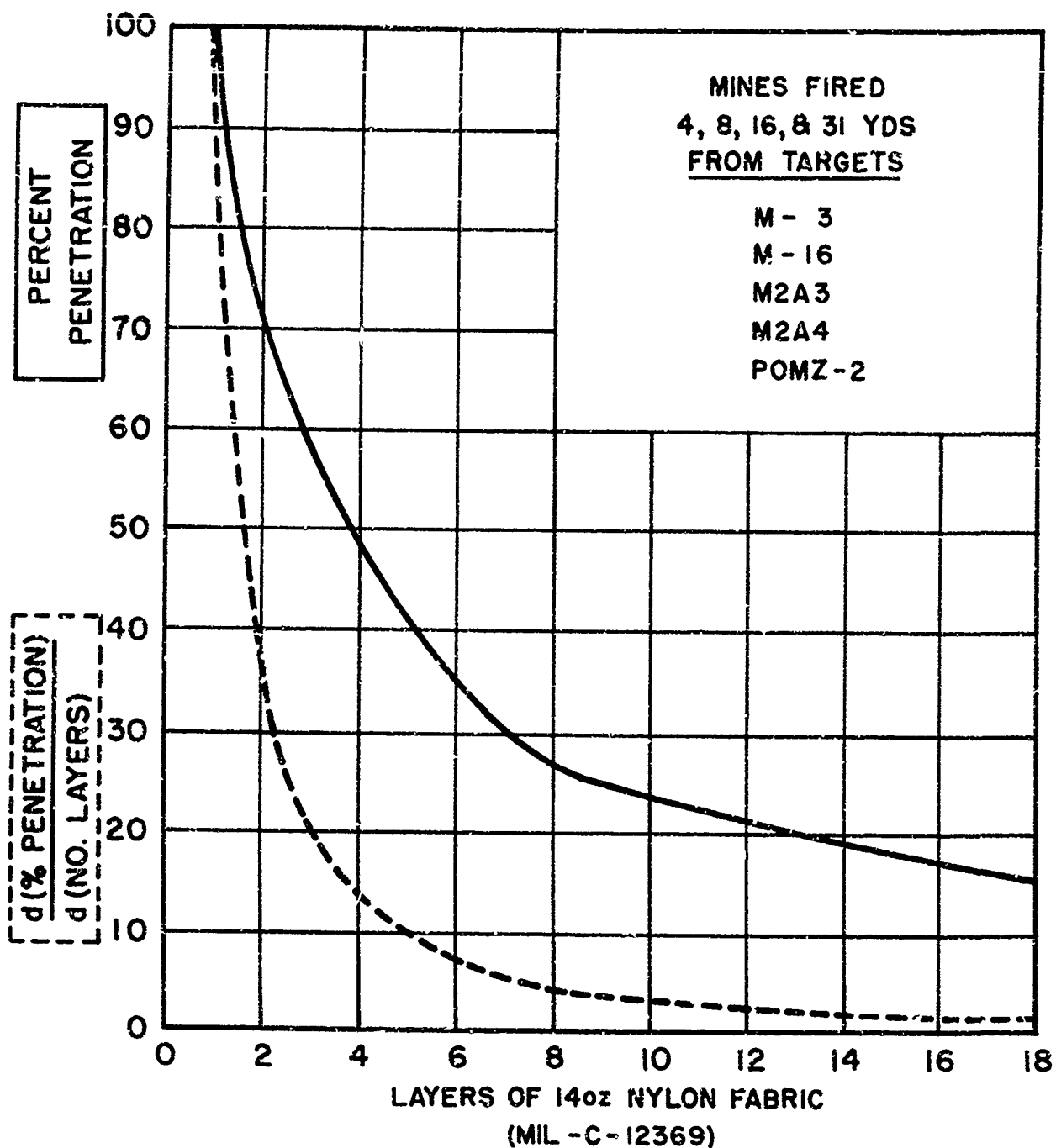


FIG. 5 PENETRATION OF MINE FRAGMENTS THROUGH BALLISTIC NYLON FABRIC LAYERS (ACCUMULATIVELY). CHART ASSUMES THAT THE FIRST LAYER HAD 100% FRAGMENT PENETRATION.

The prime consideration in the development of the mine clearance armor ensemble was protection without compromising operational efficiency. Tailoring, appearance and drape were secondary considerations. The ensemble was developed to be a specialized combat uniform, and it was recommended that it be considered solely as a functional combat uniform.

Mine detection equipment is provided to troops as a kit; it is therefore recommended that the mine clearance armor ensemble be furnished as a component of the kit. Because each soldier, in combat, is expected to have in his possession a helmet and armored vest, the kit would contain supplementary armor to protect the face, neck, lower torso and groin, and extremities.

The entire ensemble, exclusive of the face and neck protection, should be worn by all members of the mine clearance team. The face and neck protection do not have to be worn by the security men, relief or reserve, and get-away personnel.

Mine Clearance Armor Ensemble

The mine clearance ensemble was developed, giving consideration to the areas of vulnerability and weight requirements, without compromising its functionability and the protection it would provide. In the development of the ensemble, prime consideration was given to the use of standard armor and the facile provision for integration of future developments.

Armored Vest (20)

Because the armored vest has proved itself in battle, it was considered for use to protect the most vulnerable area of the body - the torso. The armored vest then served as the basis around which other components of the ensemble would be developed. These other components would not, however, have greater protective characteristics than the vest affords to the upper torso, which requires the greatest protection. These guidelines served as a control for the total weight of the ensemble.

The armored vest is constructed of 12 plies of ballistic nylon fabric, (21) spot laminated with a modified phenolic resin or button stitched. Figure 5 indicates that 12 layers of nylon cloth, which constitutes the vest, will stop 79 percent of all mine fragments penetrating the first layer. These data correlate very closely with performance characteristics of the armor as determined during the Korean War. (15) (16) (17) It is generally stated that the armored vest stopped approximately 75 percent of all battlefield fragments during the Korean War.

Helmet

The helmet shell (22) and nylon liner (23) (24) assembly has slightly more resistance to fragmentation penetration than the armored vest. Therefore,

it is reasonable to assume that the helmet assembly will afford the same level of protection against mine fragments as does the armored vest. The helmet shell and nylon liner assembly should stop approximately 80 percent of the mine fragments impinging upon it.

Armored Trousers

The abdomen and coccyx, as well as the lower extremities, are protected from fragment penetration by trousers constructed from ballistic nylon cloth. Because the abdomen and coccyx are considered to be more critical and vulnerable areas than the extremities, they are protected by 12 layers of armor cloth, while the extremities and buttocks are covered with 4 plies of nylon cloth. Figure 5 indicates that 12 plies of ballistic nylon cloth will stop approximately 79 percent of the mine fragments penetrating the first layer, while the lower extremities and the buttocks are protected from approximately 50 percent of the mine fragments penetrating the first layer of fabric. An overlapping flap arrangement of ballistic fabric covering the abdomen (Fig. 6) permits the placement of 12 plies of nylon fabric in that area without significant restriction of waist or hip movements.

Armored Sleeves

To complement the armored vest with protection for the upper extremities, sleeves were fabricated of 4 plies of ballistic fabric. The sleeves are attached to a non-ballistic jerkin which may be worn over the armored vest. The armored sleeves will stop approximately 50 percent of all fragments penetrating the first layer of nylon fabric. To permit the mine clearance personnel to bare their arms during a probing operation, the sleeves were slit, allowing them to be folded back as shown in Fig. 7.

Armored Visor

The development of head and face protection for mine clearance personnel was accomplished as a project separate from the mine clearance suit. Consideration was given to highly specialized physical, psychological, and compatibility problems that are present when the head and face are enclosed. Because this development used rigid plastic laminated armor materials and transparent armor materials, fabrication and engineering techniques were developed simultaneously with the visor.

The helmet and liner is a basic issue to every combat soldier. Since the steel helmet and nylon liner assembly provides slightly more ballistic protection than is provided by the armored vest, it served as a base for the development for mine clearance face protection. A visor was developed to supplement the helmet and cover the face and neck with armor.

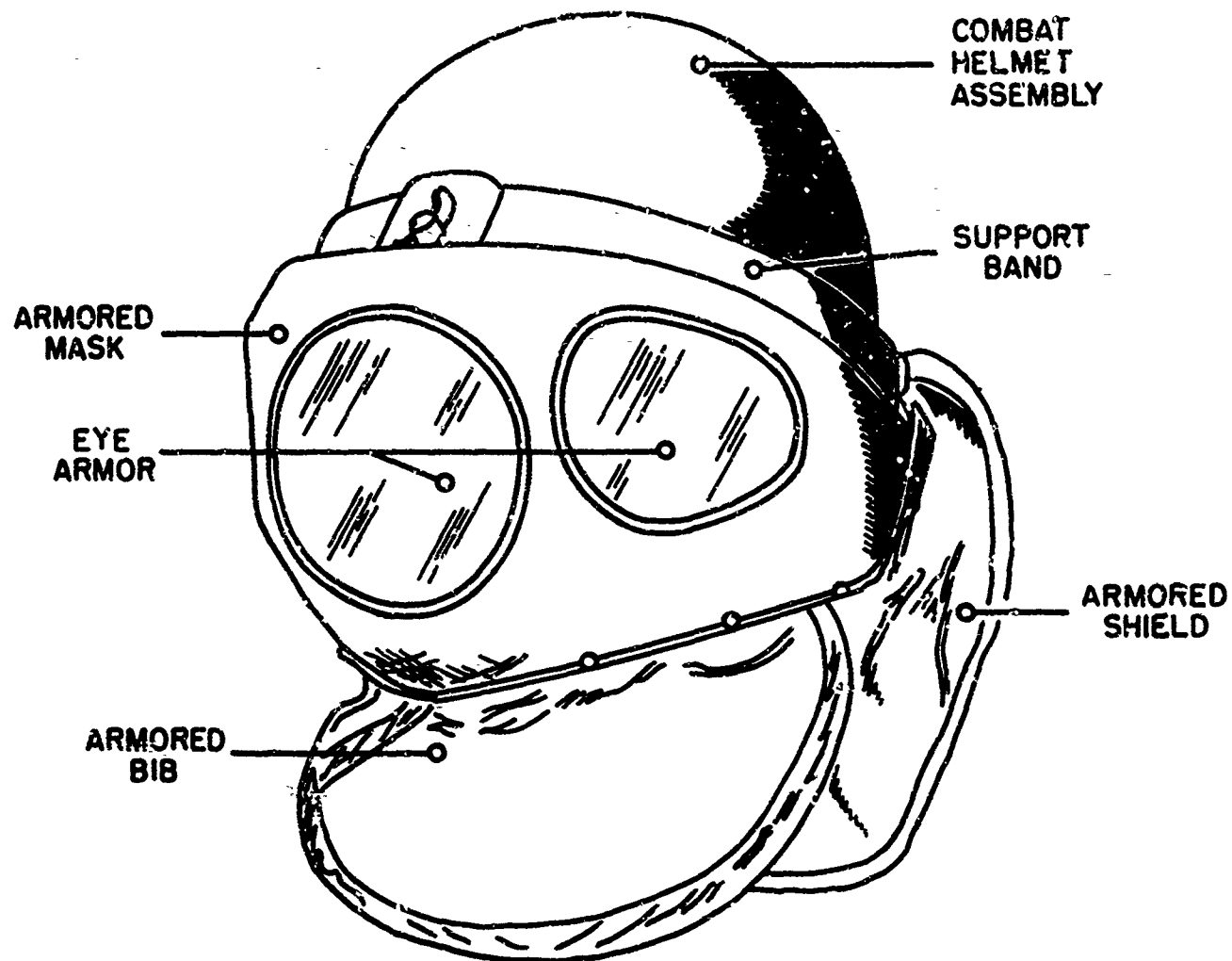


FIG. 6

ARMORED TROUSERS SHOWING THE FLAP CONFIGURATION WITH 12 PLYES OF BALLISTIC ARMOR TO COVER THE ABDOMEN AND GROIN AREA.



FIG. 7 ARMORED SLEEVES ATTACHED TO NON-BALLISTIC JERKIN WHICH IS WORN OVER A STANDARD ARMORED VEST. SLEEVES ARE ROLLED BACK AS IF FOR A PROBING OPERATION.



**FIG. 8 MINE CLEARANCE PROTECTIVE
ASSEMBLY FOR HEAD, FACE AND
NECK.**

The visor consists of five major components (Fig. 8).

1. Support Band: A plastic retaining device to hold the visor on the helmet. It need not have ballistic resistant properties.
2. Mask: Rigid armor to cover the face. It is a six-ply, laminated nylon structure similar to the structure of the Liner, Soldier's Steel Helmet. (23) (24) The protective characteristics of the mask are equivalent to that of eight plies of ballistic nylon fabric (Fig. 5). It is expected to stop approximately 70 percent of all fragments penetrating the first layer.
3. Eye Armor: Three replaceable transparent armor plastic laminates, a circular front piece flanked by oval side pieces are set into the mask. This arrangement provides maximum vision required for a mine clearance operation. Figure 9 shows the area of vision available through the mine clearance visor as compared to the bare-headed man. The transparent armor affords ballistic protection equivalent of 17 layers of ballistic nylon as is shown in Figure 5.

The transparent armor is a composite system, nominally 7/16 inches thick, composed of polymethyl methacrylate, polyvinyl butyral, and polyester film bonded together in that order, with two transparent adhesives. Each component of the composite armor performs a specific task in the stopping of a ballistic fragment. The hard, rigid polymethyl methacrylate, the material facing the environment, absorbs much of the energy of the initial impact. Penetration of the fragment and cracking the outer surface dissipates more of the impact energy, thus slowing down the fragment. The soft polyvinyl butyral interlayer then stops the fragment. The polyester film serves to protect the soft interlayer from the dust and dirt. The tough polyester backing of the armor film prevents the spall, resulting from the impacted facing, from becoming secondary hazards (Fig. 10).

A contributing factor in the accomplishment of ballistic resistance of laminated armor is "controlled delamination" of the components, that is, the dissipation of impact energy as a result of the separation of the laminae. Thus, the adhesive strength of the bond between the polymethyl methacrylate and the polyvinyl butyral must be controlled. Too strong a bond would reduce the ballistic limit of the armor.
4. Armored Bib: Flexible armor fixed to the front of the mask to cover and protect the front of the neck. It is constructed from six plies of nylon fabric with an outer cover made of non-ballistic waterproof neoprene-coated, nylon fabric. It stops approximately 65 percent of all mine fragments penetrating the first layer of ballistic nylon fabric.
5. Armored Shield: Flexible armor constructed similarly as the bib and offers the same level of protection is attached to the rear of the support band with quick-release fastening devices. The shield covers and protects the back of the neck.

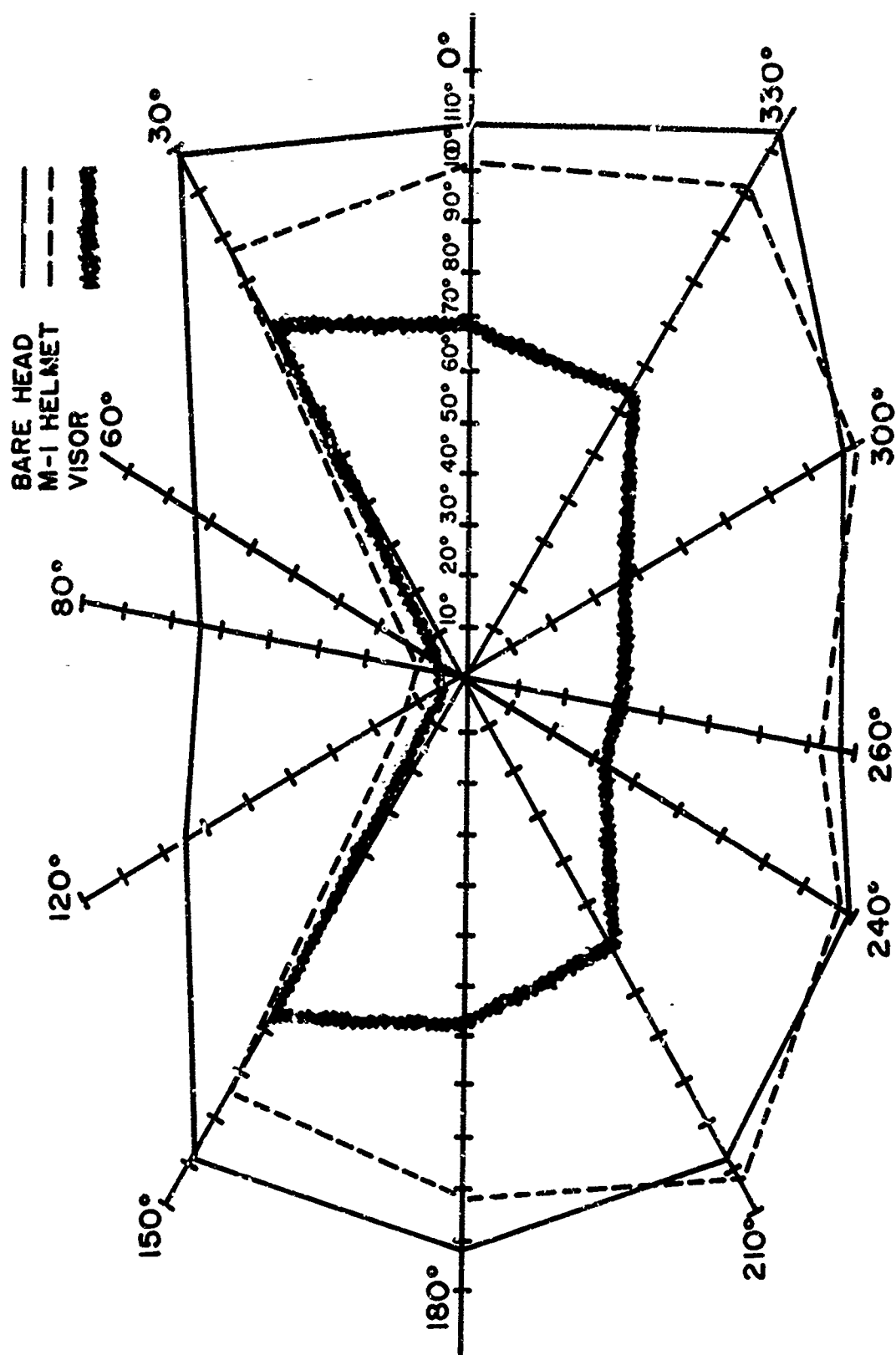


FIG. 9 AREA OF AVAILABLE VISION TO THE BARE-HEADED MAN, WHILE WEARING THE COMBAT HELMET AND WHILE WEARING THE HELMET AND MINE CLEARANCE VISOR.



a ACRYLIC PLATE



b COMPOSITE PLATE USING ACRYLIC, PVB and MYLAR

- FIG. 10 TRANSPARENT ARMOR SHOWING THE EFFECT OF NON-PENETRATING IMPACTS OF 17 GRAIN .22 CALIBER PROJECTILES.
- a ACRYLIC PLATE GENERATES SPALL WHEN IMPACTED AT ABOUT 1400 FEET PER SECOND.
 - b COMPOSITE PLATE MADE FROM ACRYLIC, POLYVINYL BUTYRAL AND MYLAR PLASTICS GENERATED NO SPALL WHEN IMPACTED AT ABOUT 1475 FEET PER SECOND.

The single size visor and its configuration is the result of a series of compromises in which weight distribution, area of vision, environmental conditions, and compatibility with mine clearance devices, armor materials and standard clothing were considered.

Weight limitations and the vulnerable body areas dictated the variable protective coverage provided by the mine clearance armor ensemble. The weight of the ensemble components is as follows:

Helmet and liner assembly	3.4 lbs
Visor	3.0
Vest	8.5
Sleeves	3.4
Trousers	<u>7.4</u>
	25.7 lbs.

The total ensemble weighs approximately 25-1/2 pounds. Every combat soldier is expected to have a helmet and armored vest in a combat zone. Thus, about 12 pounds of the mine clearance ensemble is standard issue to all combat soldiers. At the outset of a mine clearance operation, the mine clearance team would be issued only about 13-1/2 pounds of additional armor.

Compatibility

An important and all-inclusive military requirement for all combat clothing and headgear is that newly developed materiel must be compatible with all standard clothing and equipment. To achieve this compatibility, information was required regarding the duties, tactics, and environments to which mine clearance personnel would be subjected. This information was obtained by studying training manuals (25) and training films (26) (27) (28) (29) and through interviews and demonstrations conducted with experienced combat engineer officers and enlisted men.

Assault breaching is considered the most demanding tactical mine clearance operation. Thus, armor designed to be worn in assault breaching should be suitable for rear area mine clearance operations and other specialized demolition neutralization operations. So, the mine clearance ensemble was designed specifically for the assault breaching.

An examination of available literature revealed no reference to environmental limitations for mine clearance operations. Therefore, it is expected that mine clearance operations will be conducted in a variety of climatic environments ranging from extremely hot-wet to sub-freezing temperatures.

To introduce a minimum of new items into the Army supply system, the mine clearance ensemble was designed to be worn as an outer garment over hot weather

clothing or as a liner of the cold weather uniform. To conform with standard camouflage practices, the outer ply of the nylon dyed Olive Green 106. The trousers and sleeves, turned inside-out, could provide desert camouflage.

The mine clearance armor ensemble presented no sizing problems when it was worn as an outer garment, even when it was worn inside-out. When worn as a liner with the cold-wet uniform, a sizing study indicated that three sizes; small, medium, and large, should fit 95 percent of the Army population. The addition of an extra-small and extra-large size would not be warranted unless the ensemble was intended for general use throughout the Army. As a result of the sizing study, a suggested sizing tariff for the mine clearance ensemble was recommended as follows: 30 percent small, 50 percent medium, and 20 percent large. This tariff would be applicable to both the upper and lower torso components.

The increased weight of the mine clearance ensemble worn in hot environments would impose a heat stress upon the troops. Because the clearance of a mine field is a slow and deliberate operation, it was anticipated that the additional weight and accompanying thermal stress would not significantly effect the efficiency of the operation. (30)

The movement of rolling up the sleeve of the mine clearance ensemble, during a probing operation, can be easily accomplished under all circumstances except when the armor is worn as a lining under cold weather gear. In this instance, the aperture of the standard field jacket sleeve would not accommodate the bulk of the garments which it covers. It must be noted, however, that the aperture of the field jacket sleeve could not be pulled over the underwear and O.D. shirt of the cold-wet uniform to expose the forearm even when the mine clearance armor is not worn.

Donning and doffing the trousers over the leather combat boot can be accomplished easily. But, because the insulated combat boot is considerably larger than the leather boot, it must be removed prior to donning or doffing the armored trousers. Consideration was given to slitting the trousers or enlarging them. This was rejected because the circumference of the trouser opening was approximately the same as the thigh circumference; thus, a slit would be required for the full length of the trouser leg. Making the trouser leg larger would increase the weight and bulk of the trousers considerably.

The armored visor provides a universal fit. The single size visor requires no head size adjustment because it snaps onto the brim of the standard steel helmet. There is, however, a single adjustment to accommodate head length. A tape and buckle adjustment permits the mask to move vertically approximately one-half inch. A second snap was placed on the support band to permit the mask to be moved to a forward position, to accommodate the M-17 Protective Mask. The visor will fit the 95 percentile of the Army male population. The visor

is compatible with mine clearance equipment and will not interfere with the vision (Fig. 8) or hearing required to accomplish a mine clearance operation.

The fogging of transparent armor of the mine clearance visor is a problem inherent in all face and eye protective devices which enclose the face. Because the space in the visor is small compared to the volume of breath exhaled, a great quantity of saturated water vapor at body temperature will contact the inner surface of the armor lens. This condensate, in discrete droplets, causes a translucency which impedes vision. In cold environments, freezing of the droplets forms minute ice crystals which scatter light and are harder to remove than the water droplets. A continuous thin-water film of uniform thickness would be fully transparent. However, any foreign matter on the lens surface would prevent the formation of a uniform, continuous layer of water. Treatment of the lens surface with a wetting agent would tend to prevent droplet formation. The use of water soluble soaps and organic detergents have limited effectiveness as anti-fogging agents.

Test and Evaluation

After the design had been conceived and prototypes made, the mine clearance ensemble was tested, evaluated, modified and retested. Listed below are several critical tests and evaluations:

1. An informal design evaluation was conducted at Fort Devens, Mass., in December 1957, with officers and enlisted men of the 232nd Engineers, 4th Regimental Combat Team. The test was observed and evaluated by the participants, human factors engineers, and clothing design personnel. This evaluation showed that there was no difficulty in donning or doffing the armor, and that it was compatible with the standard cold-wet uniform. The ensemble was found to be compatible with mine clearance equipment which consisted of a headset, detector and power pack (Figure 11). No excessive restrictions or encumbrances were experienced in carrying out a mine clearance operation. In a withdrawal action under simulated attack, the visor was removed and a rapid evacuation of the minefield was accomplished with no encumbrances. The visor did restrict hearing and vision, but the consensus was that it would not reduce the efficiency of a breaching operation.

2. A field test of the mine clearance armor suit was conducted by the U.S. Army Quartermaster Field Evaluation Agency in 1958. (31) This test determined that a turtleneck armored collar was not satisfactory. With the exception of the collar, the suit was compatible with the cold-wet uniform. There was no difficulty in donning and doffing the uniform except removal or donning trousers over the insulated boots.

3. An engineering test of the mine clearance ensemble was conducted by the U.S. Army Quartermaster Field Evaluation Agency concurrently with a service test in 1959 (32). This test showed that mine clearance operations



FIG. 11 MINE CLEARANCE ARMOR WORN UNDER THE COLD-WET UNIFORM AND WITH TWO TYPES OF MINE DETECTORS. THE INSET SHOWS THE ARMOR AND KIT BEING USED IN THE PRONE POSITION.



FIG. 12 MINE CLEARANCE OPERATIONS WHILE ARMOR IS USED.

- A. MINE CLEARANCE TEAM PREPARE TO ENTER FIELD**
- B. PROBING FOR MINES**
- C. USING MINE DETECTOR**
- D. SENSING TRIP WIRE**
- E. EXPOSING MINE**

can be performed satisfactorily while wearing the ensemble (Fig. 12). Minor difficulties experienced were attributed to weight, bulk and heat stress imposed by the ensemble and interference with vision. The noted deficiencies were corrected wherever feasible to do so, e.g., non-elastic suspenders were provided to prevent sagging of trousers, seams were reinforced, and the visor contour was modified.

4. An engineering test of the Marine Corps mine clearance footgear was evaluated by the U. S. Army Quartermaster Field Evaluation Agency in 1959.⁽³³⁾ This test showed that the footgear did not interfere with the performance of mine clearance operations. It was recommended, however, that the footgear be worn only by those personnel using the mine detector equipment in the standing position.

5. A wound ballistics study⁽³⁴⁾ was conducted by the Directorate of Medical Research, USA Chemical Research and Development Laboratories in 1961 to determine if the mine clearance ensemble would provide protection from an exploding anti-personnel mine. The study showed that persons wearing the mine clearance ensemble with the Marine Corps sabot (footgear) will be protected against fragments from the anti-personnel mine, M-14.

Fabrication

Fabrication of the flexible components of the mine clearance armor ensemble may be easily accomplished by ordinary tailoring techniques. These components are as follows:

1. Bib and shield of visor
2. Armored vest
3. Sleeves
4. Trousers

The visor (Fig. 8), however, presented fabrication techniques that encompassed both design and engineering problems. The support band, a spring-like device, to hold the visor onto the helmet, is made by bonding coated or impregnated fabric by means of high pressure laminating. The mask was made by high pressure laminating coated ballistic nylon fabric, with a three-piece all-metal mold consisting of a split cavity and a force plug. The material in the eye ports was compressed, thus the ports were easily pushed out of the mask and required very little trimming.

The optical system of the visor presented the greatest fabrication problem of the ensemble. Eye armor use for this ensemble consists of a three-component laminate bonded with two different adhesives. Optical flaws resulting from inadequate fabrication techniques could make the laminate useless as eyepieces for mine clearance purposes.

Optical aberration which must be avoided is as follows:

1. Deviation of the line of sight is a shift in direction of the line of sight. This characteristic, when present in formed materials, is due to unequal stretching of the materials.
2. Displacement of the line of sight is a shift in position of the line of sight. This optical aberration is a function of material thickness, index of refraction, and angle of incidence.
3. Distortion is an aberration arising from variations in magnification within a small area as a result of varied thickness and/or irregularities in the contour of optical surfaces.

With the available materials, in the thickness required for effective protection, it is impossible to make optically acceptable curved eye armor. Fabrication of curved eye armor would result in stretching the outer surface and compressing the inner surface of a laminate and would probably introduce uneven surfaces and variations in thickness. The thickness required for this curved eye armor would make it virtually impossible to attain good binocular vision without grinding; and this material system used for this armor cannot be ground. Thus, mandatory use of flat eye armor limited the configuration of the visor.

The transparent armor used for this development was a laminate nominally 7/16-inches thick which was composed of polymethyl methacrylate, polyvinyl butyral and polyester film. The transparent armor is laminated by applying heat and pressure to the laminae bonded with transparent adhesive. The following two techniques were successfully used to fabricate transparent armor:

1. Flat bed compression molding.
2. Autoclave under pressure (method used for the manufacture of safety glass).

Recent Developments of Armor Materiel

The mine clearance ensemble was developed for members of a team that should, during an operation, maintain a minimum distance of 15 yards from each other. (25) New doctrine introduced in 1966 required that the mine clearance team members maintain distances greater than 15 yards between themselves. The Array testing of the nylon fabric against the fragmentation effects of anti-personnel mines (18) (19) indicated that the ensemble would provide significant protection at a distance of 4 yards from the blast center (Fig. 3). Current doctrine specifies that a minimum distance of 25 meters (27.34 yards) between members of a mine clearance operation. (35) Extrapolating from data in Figure 3, there would be a small probability of inflicting serious injury to the unarmored man 25 yards from the blast center of the M16 anti-personnel mine.

The mine clearance armor ensemble was only one of a series of armor clothing and helmets being developed for the combat soldier. Continued research and development has provided new armor materials, design techniques and tools that will serve to provide suitable armor for future requirements. Table I lists typical applications of common armor materials, their weight and level of protection.

TABLE I
ARMOR MATERIALS AND TYPICAL APPLICATIONS⁽³⁶⁾ ⁽³⁷⁾

<u>Material</u>	<u>Application</u>	<u>Areal Density/ft²</u>	<u>Threat</u>
Nylon fabric	Vest, Helmets	7.5 - 18.6 oz	Fragments
Titanium	Helmets, Vest	17.5 - 18.6 oz	High Velocity Fragments
Nylon felt	Vests	0.04- 0.9 oz	Fragments
Polycarbonate ⁽³⁸⁾	Eyeshields	8.4 oz	Fragments
Ceramic/GRP* ⁽³⁹⁾	Vests, Leg Armor	6.5 - 9.3 lbs	Small Arms
Aluminum Honeycomb ⁽⁴⁰⁾	Boots	Variable	Brissance Effect

*Glass Reinforced Plastic

More efficient armor can be designed through the use of rigid metallic or ceramic components. To provide adequate protection to the body with rigid armor and not restrict the user's function, new concepts were required for the design of systems that conform with the changing shapes and dimensions of the moving body. Techniques were developed for measuring dynamic changes of body dimensions.⁽⁴¹⁾ Increased weight that accompanies increased levels of protection would have a greater tolerance level if it was evenly distributed over the body without areas or points of concentrated pressure. A device was developed to plot pressure areas that are imposed on the dynamic body by armor systems.⁽⁴²⁾ With the aid of this instrument and knowledge of body dimensional changes, armor can be designed so that maximum protection may be provided with the acceptable parameters of fit, comfort, weight distribution and the dynamic response required for a designated mission.

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APPENDIX

The mine clearance ensemble has been considered and examined for a number of specific applications. Some agencies conducted tests, others evaluated the available data. The following is a discussion of several proposed applications.

a. Fuze Handler's Protective Garment

A protective garment was required by the Harry Diamond Ordnance Fuze Laboratories (1960) for personnel who were to transfer sensitive fuzes from an environmental test chamber to an armored box for transportation to the next test station or to a neutralization area. Tests were conducted to determine the effectiveness of the material system against the hazard of exploding fuzes.

Three test panels, each made of 12 plies of ballistic nylon fabric, backed by a soft pine wood block, were exposed to the explosive effects of fuzes. Panels number 1 and 2 were each tested with fuzes T906 from a distance of 28 and 60 inches, respectively. The first panel, 28 inches from the fuze, collected 648.6 milligrams of fragments; panel number 2, 60 inches from the blast, collected 384.5 milligrams of fragments. Panel number 3, 36 inches from fuze T178, collected 776.2 milligrams of fragments. Seven fragments averaging three grains each, three fragments averaging 2 grains each, and one fragment of 1.7 grains passed through panels 1, 2 and 3, respectively, and were imbedded in the wooden backstop. Figure A shows the percentage of fragments that are stopped by the accumulative layers of nylon, assuming that the first layer had 100 percent fragment penetration. Panel number 3 apparently had been exposed to the worse conditions; its penetration resistance characteristics, as shown on Figure A, are similar to that of fabrics exposed to detonations of anti-personnel mines shown in Figure 5. Thus, extrapolation to 18 layers of nylon appear to be reasonable, thereby predicting the penetration resistance capabilities of the transparent armor.

The Diamond Ordnance Fuze Laboratories required frontal protection only and suggested that the armor material be incorporated in differently designed garments.

b. Fire Fighter's Suit

An inquiry was made by the Safety Director Ordnance Weapons Command (1959) regarding the suitability of the ensemble for protecting firemen who enter into areas that may contain a potentially explosive element. Without specific information regarding the nature of the explosive particles, few conclusions can be drawn. The nylon fabric has a melting range in the vicinity of 375°F. The effectiveness as armor would be expected to be prolonged if it were worn under a reflective garment. The multi-layers of the garment would also act as an insulator against heat.

c. Demolitions Disposal

The U. S. Naval Weapons Laboratory tested the mine clearance ensemble and recommended it favorably to the U. S. Explosive Ordnance Disposal Facility (1965). The U. S. Army Natick Laboratories had suspended all future work with the ensemble, but had provided procurement information and offered technical assistance if the U.S. Navy wished to acquire additional items. Inquiries regarding full body armor were also made by the U.S. Naval Ammunition Depot Earle (1969).

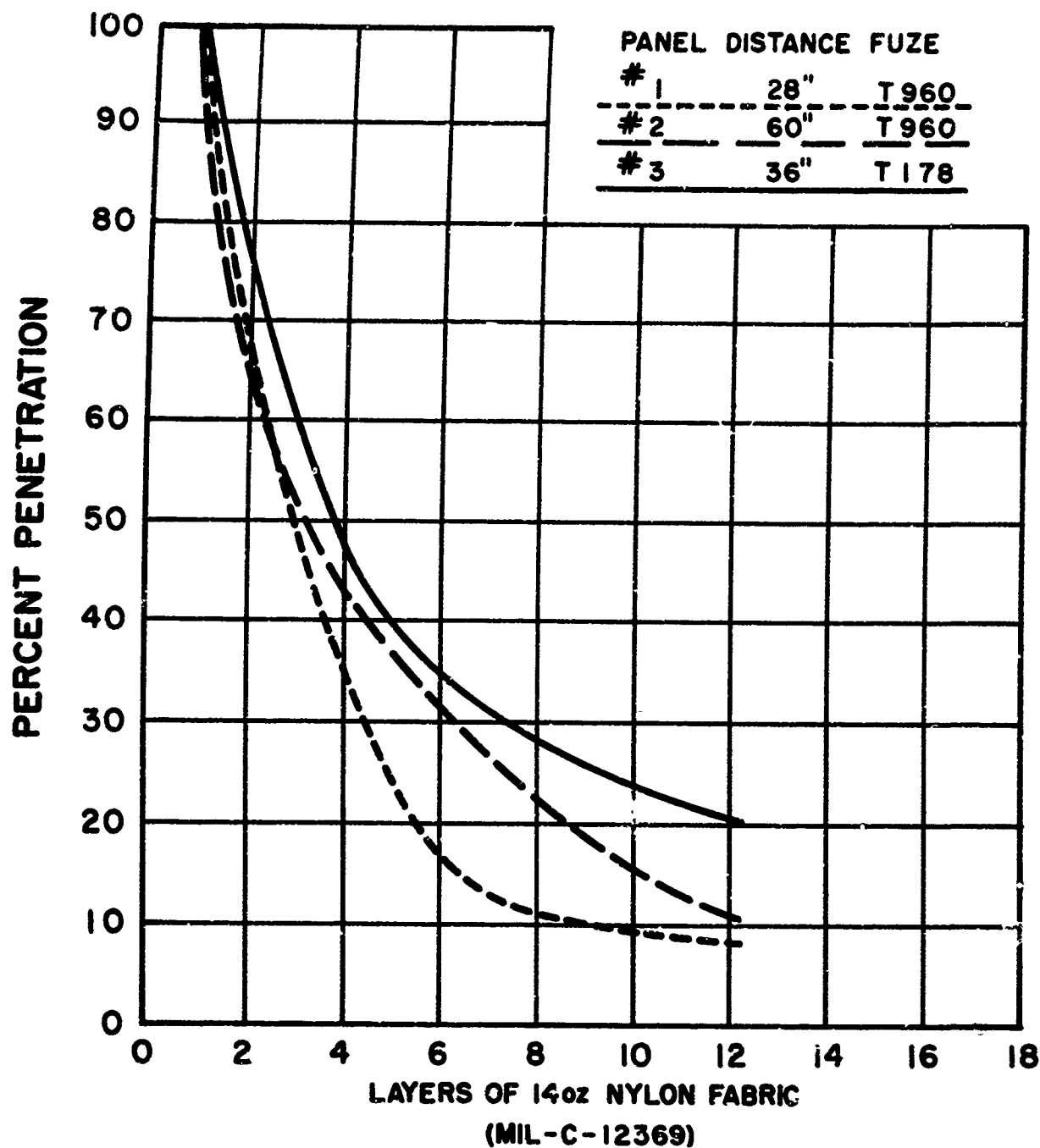


FIG. A PENETRATION OF FUZE FRAGMENTS THROUGH BALLISTIC NYLON FABRIC LAYERS (ACCUMULATIVELY). CHART ASSUME THAT THE FIRST LAYER HAD 100% FRAGMENT PENETRATION.